DEVELOPMENT OF EDM TOOL FOR PRODUCING TITANIUM ALLOY AUTOMOTIVE VALVE APPLICATION

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ABSTRACT

This paper presents the development of EDM tool for producing titanium alloy automotive valve application. Electric discharge machining (EDM) is a non-traditional machining processes that involved a transient spark discharges through the fluid due to the potential difference between the electrode and the work piece. The objective of this paper is to investigate how the peak current, servo voltage, pulse on- and off-time in EDM effect on Material Removal Rate (MRR), Tool Wear Rate (TWR). The experimental control parameters were being optimized according to their various machining characteristics namely Material Removal Rate (MRR), Tool Wear Rate (TWR) using copper as the electrode and also copper as the workpiece. Design of experiment (DOE) technique is used to determine the optimum machining parameters for this machining characteristic. Taguchi method has been used for the construction, layout and analysis of the experiment for MRR and TWR machining characteristic. The use of Taguchi method in the experiment saves a lot of time and cost of preparing and machining the experiment samples. Therefore, an L9 Orthogonal array which was the fundamental component in the statistical design of experiments has been used to plan the experiments, Analysis of Variance (ANOVA) is used to determine the optimum machining parameters for this machining characteristic. The result shown the peak current are most significant factor that affect material removal rate(MRR) and tool wear ratio (TWR) since the parameter bring major effect to MRR and TWR. As conclusion, the development of EDM tool is achieved and got the optimum parameter for MRR and TWR.

ABSTRAK

Kertas kerja ini membentangkan pembuatan alat EDM untuk menghasilkan aloi titanium untuk diaplikasikan kepada injap automotif. Pemesinan pelepasan elektrik (EDM) adalah satu proses pemesinan bukan tradisional yang melibatkan pelepasan percikan electrik melalui cecair kerana perbezaan potensi antara elektrod dan bahan kerja. Objektif kertas ini adalah untuk menyiasat bagaimana puncak semasa, voltan servo, nadi di dalam dan di luar masa dalam kesan EDM pada kadar pembuangan bahan (MRR), kadar penghakisan alat (TWR). Parameter kawalan eksperimen sedang dioptimumkan mengikut ciri-ciri pemesinan pelbagai mereka iaitu kadar pembuangan bahan (MRR), kadar penghakisan alat (TWR) menggunakan tembaga sebagai elektrod dan juga tembaga sebagai bahan kerja. Reka bentuk eksperimen teknik (DOE) digunakan untuk menentukan parameter pemesinan optimum untuk ciri-ciri mesin ini. Kaedah Taguchi telah digunakan untuk pembinaan, susun atur dan analisis eksperimen untuk MRR dan TWR pemesinan ciri. Penggunaan kaedah Taguchi dalam eksperimen menjimatkan banyak masa dan kos penyediaan dan pemesinan sampel eksperimen. Oleh itu, pelbagai ortogon L9 yang merupakan komponen penting dalam reka bentuk statistik eksperimen telah digunakan untuk merancang eksperimen dan Analisis Varian (ANOVA) digunakan untuk menentukan parameter pemesinan optimum untuk ciri-ciri mesin ini. Hasilnya ditunjukkan semasa puncak adalah faktor yang paling penting yang mempengaruhi kadar pembuangan bahan (MRR) dan nisbah memakai alat (TWR) sejak parameter membawa kesan yang besar kepada MRR dan TWR. Kesimpulanya penghasilan alat EDM telah berjaya dan parameter pemesinan optimum telah dapat untuk MRR and TWR.

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CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Electrical Discharge Machine (EDM) is now become the most important accepted technologies in manufacturing industries since many complex 3D shapes can be machined using a simple shaped tool electrode. Electrical Discharge Machine (EDM) is an important ‘non-traditional manufacturing method’ and has been accepted worldwide as a standard processing manufacture of forming tools to produce plastics mouldings, die castings, forging dies and etc. New developments in the field of material science have led to new engineering metallic materials, composite materials, and high tech ceramics, having good mechanical properties and thermal characteristics as well as sufficient electrical conductivity so that they can readily be machined by spark erosion.

At the present time, Electrical Discharge Machine (EDM) is a widespread technique used in industry for high precision machining of all types of conductive materials such as: metals, metallic alloys, graphite, or even some ceramic materials, of whatsoever hardness. Electrical Discharge Machine (EDM) technology is increasingly being used in tool, die and mould making industries, for machining of heat treated tool steels and advanced materials (super alloys, ceramics, and metal matrix composites) requiring high precision, complex shapes and high surface finish. Traditional machining technique is often based on the material removal using tool material harder than the work material and is unable to machine them economically. An Electrical Discharge Machining (EDM) is based on the eroding effect of an electric spark on both the electrodes used. Electrical Discharge Machining (EDM) actually is a process of utilizing the removal phenomenon of electrical-discharge in dielectric. Therefore, the electrode plays an important role, which affects the material removal rate and the tool wear rate.

1.2 PROJECT BACKGROUND

Electrical discharge machining or in short, EDM is based on the concept of using electrode to erode a work piece by using electrical sparks. An electrical spark is created between an electrode and a work piece. The spark is visible evidence of the flow of electricity. This electric spark produces intense heat with temperatures reaching 8000 to 12000 degree Celsius, melting almost anything. The spark is controlled very carefully and localized in order to prevent it from affecting other surfaces except for the surface. EDM process usually does not affect the heat treat below the surface. With EDM electrode, the spark always takes place in the dielectric of kerosene. The conductivity of the kerosene is controlled carefully to provide an excellent environment for the EDM process. Kerosene as coolant and flushes away the eroded metal particles.

There are a few types of flushing which are pressure flushing, jet flushing, injection flushing and suction flushing. Among those types of flushing there are advantages and disadvantages of them. In order to improve the flushing condition, it involves some form of relative motion between tool and work piece. Flushing is a very important function in any Electrical Discharge Machine (EDM) operation. It not only serves to remove the eroded debris from the spark-gap region but also has various other functions which highly influence the outcome of this machining process. Although the influence of flushing as a whole some requirement on the efficiency and stability of machining conditions in EDM has been extensively investigated, little has been reported concerning the effects of the various individual flushing techniques that are available in the industry. Improper flushing will cause erratic cutting and will increase machining time.

The Design of Experiment (DOE) using the Orthogonal Array is use to optimization of the single response characteristic. Consequently, Analysis of Variance (ANOVA) and the F test is also used to determine the significant machining parameter and obtain optimal combination levels of machining parameters. Therefore, some investigate needs to be for getting the best solution of the product by using the electrical discharge machining (EDM). The generally, the expected result that have been found that the higher material removal rate (MRR), the lower tool wear rate (EWR), better surface roughness and also no secondary machining.

1.3 PROBLEM STATEMENT

In electrical discharge machine (EDM), improper choose of the electrode material may cause of poor machining rate or performance. This is due to material removal rate (MRR) characteristic. Less material removal rate (MRR) needs more time for machining process and become waste and not goods for production. The second problem is it will decrease the accuracy of the product because influence of the tool wear rate (TWR) characteristic. The accuracy of the product occurs maybe because the tool wear rate (TWR) is high or material removal rate (MRR) is not suitable. Furthermore, electrode wear imposes high costs on manufacturers to substitute the eroded complicated electrodes by new ones for die making. In order to increase the machining efficiency, erosion of the work piece must be maximized and that of the electrode minimized in EDM process. Therefore, studying the electrode wear and related significant factors would be effective to enhance the machining productivity and process reliability.

1.4 OBJECTIVE OF THE PROJECT

The objective of this project is for design and fabrication mould to produce EDM tool for automotive valve application. There are some objectives of this research;

1) Design and fabrication of EDM tool for producing automotive valve application.
2) To optimize the materials removal rate and tool wear rate in the EDM process using Taguchi Method.

1.5 SCOPE OF THE PROJECT

This research will focus on how to design and fabrication mould to produce EDM tool for automotive valve application. In this research, I limited to machining by using CNC lathe machine to produce electrode and EDM die sinking is being used to make the mould. Also I am studying the parameters involve from both machine. The research scope is limited to machining parameters refers to electrical parameters on Electrical Discharge Machine (EDM) i.e. polarity, pulse-on-duration, discharge current, discharge voltage and non-electrical parameter like jet flushing pressure, machining diameter and machining depth . The scope should be limited in this experiment due to low cost and time. Besides, only cooper is the tool electrode that used. The reason for using this only copper electrode is regarding to cost limitation and availability. Beside, this paper project can gain a lot of knowledge and get more understanding about the Electric Discharge Machine (EDM).

1.6 SUMMARY

Chapter 1 has been discussed briefly about project background, problem statement, objective and scope of the project. This chapter is as a fundamental for the project and act as a guidelines for project research completion. Generally, this thesis consists of five chapters. Chapter 1 that has you read is the introduction about this study. Chapter 2 is the review of literature which discusses methods and findings previously done by other people which are related to the study. Chapter 3 is the Methodology which explains the approaches and methods used in performing the thesis. Chapter 4 is the chapter which reports the outcomes or results and discussion from the project and chapter 5 consists of the recommendation and conclusion.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

One of the scope studies is literature review. This analysis will run works as guide. It will give part in order to get the information about electrical discharge machine (EDM) and will give idea to operate the test. From the early stage of the project, various literature studies have been done. Research journals, books, printed or online conference article were the main source in the project guides. This part will include almost operation including the test, history, machining properties and results. History of the Electrical Discharge Machine (EDM) will be story little bit in this section. Literature review section work as reference, to give information and guide base on journal and other source in the media.

2.2 HISTORY OF ELECTRICAL DISCHARGE MACHINE (EDM)

In 1770 English scientist Joseph Priestly firstly invented the erosive effect of electrical discharge machining. After that in 1930s, the machining of metals and diamond with electrical discharges has been done. Due to evaluation of spark, erosion was caused by intermittent arc discharges occurring in air between the electrode and workpiece which is connected to a DC power supply. Overheating of the machining area restricts the applications of this process, so it is known as "arc machining" (Ho, K.H., Newman, S.T., 2003). In 1943 at the Moscow University revolutionary work on electrical discharge machining was carried out by two Russian scientists, B.R. and N.I.

Lazarenko (Lazarenko, B.R., 1943). Refined and a controlled process for machining of materials was developed by analyzing the destructive effects. It becomes easy to maintain and control gap between the electrode and workpiece with the introduction of RC (resistance–capacitance) relaxation circuit in 1950s, which provided the first consistent dependable control of pulse times and also a simple servo control circuit.

Later stage RC circuit used as the model for successive developments in EDM technology. In America at same time three employees came up with same results by using electrical discharges to remove broken taps and drills from hydraulic valves. With the reference of this work vacuum tube EDM machine and an electronic circuit servo system that automatically provided the proper electrode to- workpiece spacing (spark gap) for sparking, without contact between the electrode and the workpiece (Jameson, E.C., 2001).

In 1980s with the initiation of Computer Numerical Control (CNC) in EDM brings remarkable advancement by improving the efficiency of the machining operation. EDM machines have become so stable with the regular improvement in the process, so that these can be used for long interval of time under monitoring by an adaptive control system. This process enables machining of any material, which is electrically conductive, irrespective of its hardness, shape or strength (Abu Zeid O.A., 1997). The improvement of EDM have since then been intensely sought by the manufacturing sector yielding enormous economic benefits and generating keen research interests.

2.3 DIE-SINKING EDM MACHINE

In present study, the machine will be used is Die-sinking EDM. Die-sinking EDM machines are also known as ram or vertical EDMs. The equipment used to perform the experiments was a die-sinking EDM machine of type Sodick AQ55L EDM. Also, a jet flushing system in order to assure the adequate flushing of the EDM process debris from the gap zone was employed. The dielectric fluid used for the EDM machine was Vitol-2 kerosene. The electrodes used were made of electrolytic copper and the polarity was negative.

Die-sinking EDM has four sub-systems that are:

1. DC power supply to provide the electrical discharges, with controls for voltage, current, duration, duty cycle, frequency, and polarity.

2. Dielectric system to introduce fluid into the voltage area/discharge zone and flush away work and electrode debris, this fluid is usually a hydrocarbon or silicone based oil.

3. Consumable electrode, usually of copper or graphite.

4. Servo system to control in feed of the electrode and provide gap maintenance.

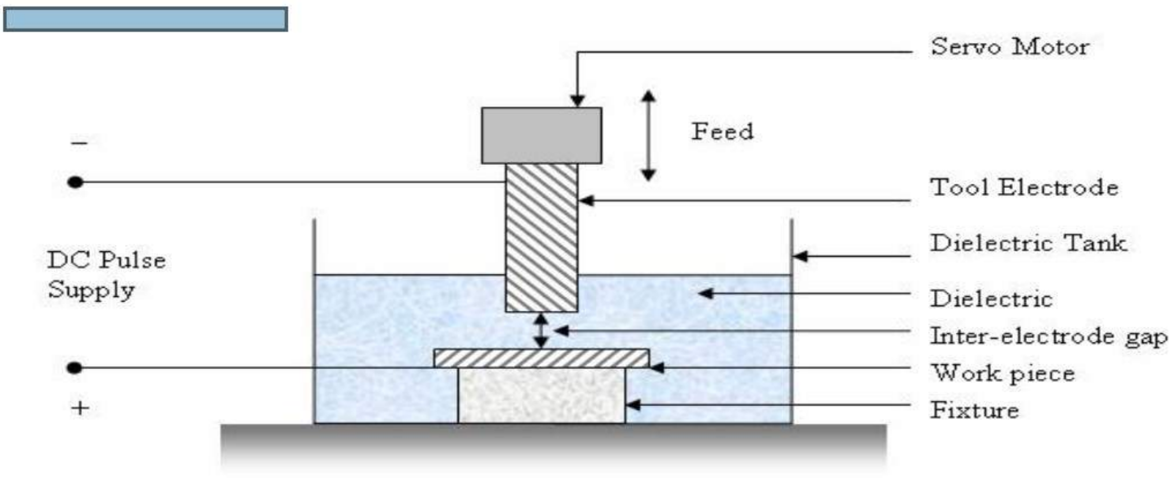

Figure 2.1: Schematic of an Electric Discharge Machining (EDM) machine tool.

Source: Sourabh Kumar Saha, May (2008)

The schematic of an EDM machine tool is shown in Figure 2.1. The tool and the workpiece form the two conductive electrodes in the electric circuit. Pulsed power is supplied to the electrodes from a separate power supply unit. The appropriate feed motion of the tool towards the workpiece is generally provided for maintaining a constant gap distance between the tool and the workpiece during machining. This is performed by either a servo motor control or stepper motor control of the tool holder. As material gets removed from the workpiece, the tool is moved downward towards the workpiece to maintain a constant inter-electrode gap. The tool and the workpiece are plunged in a dielectric tank and flushing arrangements are made for the proper flow of dielectric in the inter-electrode gap, (Sourabh Kumar Saha, May 2008)

Typically in oil die-sinking EDM, pulsed DC power supply is used where the tool is connected to the negative terminal and the workpiece is connected to the positive terminal. The pulse frequency may vary from a few kHz to several MHz. The inter electrode gap is in the range of a few tens of micro meter to a few hundred micro meter. Material removal rates of up to 300mm3/min can be achieved during EDM. The surface finish (Ra value) can be as high as 50 µm during rough machining and even less than 1 µm during finish machining,(Sourabh Kumar Saha, May 2008).

2.4 MACHINING PARAMETER SELECTION

The Process parameters can be divided into different categories i.e. electrical, non-electrical Parameters, electrode parameters, powder parameters etc. shown in Figure 2.2 below:

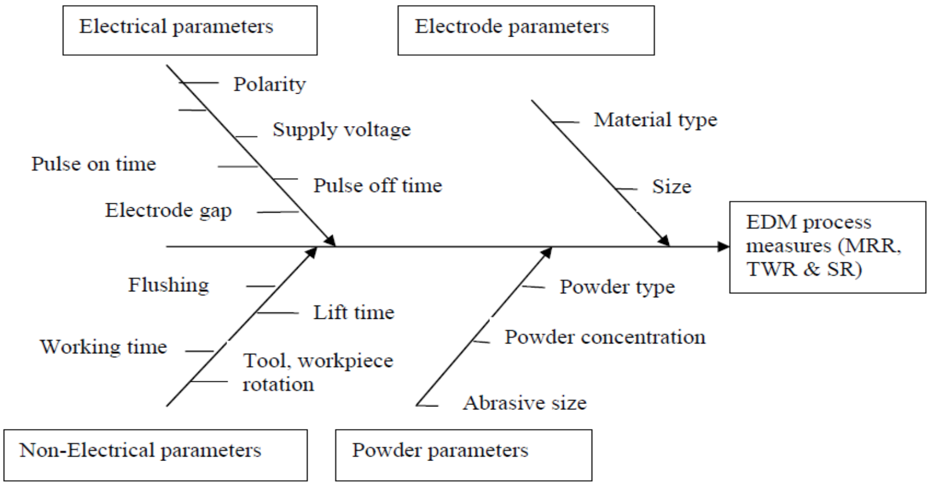

Figure 2.2: Process parameters and performance measures of EDM Process a cause and effect diagram

Source: Sharanjit Singh and Arvind Bhardwaj, (2011)

In the section, the elements considered in measuring EDM performance are MRR, electrode wear (EW), recast layer, surface quality (Ra) and effect of electrical and non-electrical parameter. Seven (7) factors are selected with a combination of four (4) electrical parameters and three (3) non-electrical parameters. Machining depth and machining diameter were selected for the control factors because they affected MRR, EWR and SR analysis.

There are two major groups of parameters that have been discovered and categorized:

1) Non-electrical Parameters

1). Pulse flushing pressure

2). Machining diameter

3). Machining Depth

2) Electrical Parameters

The input parameters considered in this study are defined as follows:

1) Polarity (A):
2) Pulse on time (B):
3) Peak current (C):
4) Power supply voltage (D)

Some of the important parameter implicated in the EDM manufacturing process are the following one:

1. Polarity (A): The polarity of the electrode can be either positive or negative. But the excess material is removed from side which is positive. When series discharge starts under the electrode area andpasses through the gap, which creates high temperature causing material evaporation at the faces of both the electrode

2. Pulse on time (B): The duration of time (μs), the current is allowed to flow per cycle. Material removal is directly proportional to the amount of energy applied during on-time. Amount of energy is really controlled by the peak current and the length of the on-time.

3. Peak current (C): The Peak current (Ip) is a measure of the power supplied to the discharge gap. A higher current leads to a higher pulse energy and formation of deeper discharge craters. This increases the material removal rate (MRR) and the surface roughness (Ra) value. It is expressed in amperes.

4. Power supply voltage (D): Before current can flow, the open gap voltage increases until it has created an ionization path through the dielectric. Once the current starts to flow, voltage drops and stabilizes at the working gap level. The present voltage determines the width of the spark gap between the leading edge of the electrode and workpiece.

The output parameters considered are defined as follows.

1) *Metal removal rate (MRR)* can be express as:

$$\textbf{MRR (g/min)}= \frac{\textbf{WRW (workpiece removed weight)}}{\textbf{T (period of machining time in minuter)}} \qquad (2.1)$$

2) For Tool Wear Rate (EWR) express as :

$$\textbf{TWR} = \frac{\mathbf{1000 \times W_e}}{\boldsymbol{\rho}_\mathbf{e} \times \mathbf{t}} \ (\mathbf{mm^3/min}) \qquad (2.2)$$

2.5 FLUSHING

The most important in EDM is flushing because eroded particle must be removed from the gap for efficient cutting. Flushing also brings fresh dielectric oil into the gap and cools the electrode and the work piece. The deeper the cavity will bring the greater the difficulty for proper flushing. Improper flushing would cause erratic cutting. This in turn increases machining time. Under certain machining conditions, the eroded particles attach themselves to the workpiece. This prevents the electrode from cutting efficiently. It is then necessary to remove the attached particles by cleaning the workpiece. The danger of arcing in the gap also exists when the eroded particles have not been sufficiently removed. Arcing occurs when a portion of the cavity contains too man eroded particles and the electric current passes through the accumulated particles. This arcing causes an unwanted cavity or cavities which can destroy the workpiece. Arcing is most likely to occur during the finishing operation because of the small gap that is required for finishing. New power supplies have been developed to reduce this danger (http://www.reliableedm.com).

Proper flushing depends on the volume of oil being flushed into the gap, rather than the flushing pressure. High flushing pressure can also cause excessive electrode wear by making eroded particles bounce around in the cavity. Generally, the ideal flushing pressure is between 3 to 5 psi. (0.2 to 0.33 bars) Efficient flushing required a balance between volume and pressure. Rough operations, where there is a much larger arc gap; require high volume and low pressure for the proper oil flow. Finishing operations, where there is a small arc gap, requires higher pressure to ensure proper oil flow.Often flushing is not a problem in a roughing cut because there is a sufficient gap for the coolant to flow. Flushing problem usually occur during finishing operations. The smaller gap makes it more difficult to achieve the proper oil flow to remove the eroded particles, (Dorf,R.C, and Kusiak, Andrew, 1994).

In the EDM process, four type of flushing can be used. There are pressure, suction, external and pulse flushing. Each job needs to be evaluated to choose the best flushing method. For this project, the pulse flushing will be used. (http://www.reliableedm.com). Pressure flushing also called injection flushing is the most commen and preffered method for flusing shown in Figure 2.3. One great advantages of presure flusing is that the operator can visually see the amount of oil that is being used for flushing.

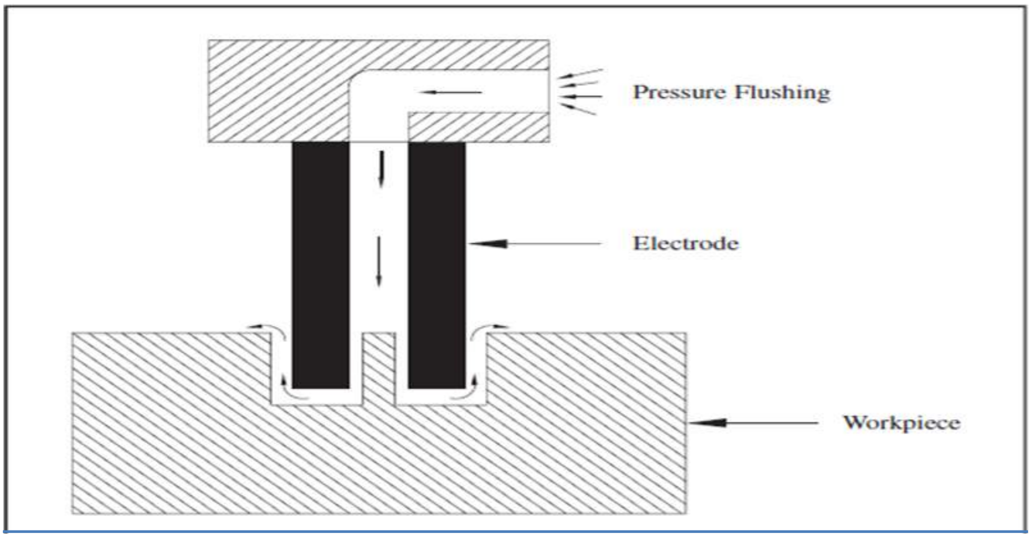

Figure 2.3: The electrode Orbit in the workpiece (http://www.reliableedm.com)

2.6 SUMMARY

This chapter discussed about the analysis that will run works as guide. It will give part in order to get the information about electrical discharge machine (EDM) and will give idea to operate the test. The Process parameters can be divided into different categories i.e. electrical, non-electrical Parameters, electrode parameters and powder parameters The some of the important parameter implicated in the EDM manufacturing processare are Polarity (A), Pulse on time (A) and Peak current (C). In the EDM process, four type of flushing can be used. There are pressure, suction, external and pulse flushing. For this project, the pulse flushing will be used.

CHAPTER3

METHODOLOGY

3.1 INTRODUCTION

In this chapter generally discusses about methodology of the project, with a focus on electric discharge machine (EDM) experiment and machining.. This section contains the methodology to conduct this study. Methodology involves the problem identification and solving, Design of Experiment (DOE), and detail experimental design. Roughly, this project consists of two semesters. For semester 1 will be doing the proposal, literature review and methodology planning. The study of electric discharge machine (EDM) also include in semester one. This all gather in the semester one. The semester two conclude the preparation of experimental tools and work pieces, running experiment, get data collection do the analysis. The documentation and report writing will be done after that.

3.2 FLOW CHART OF EXPERIMENT

Figure 3.1 shown the flow chart to run the experiment.

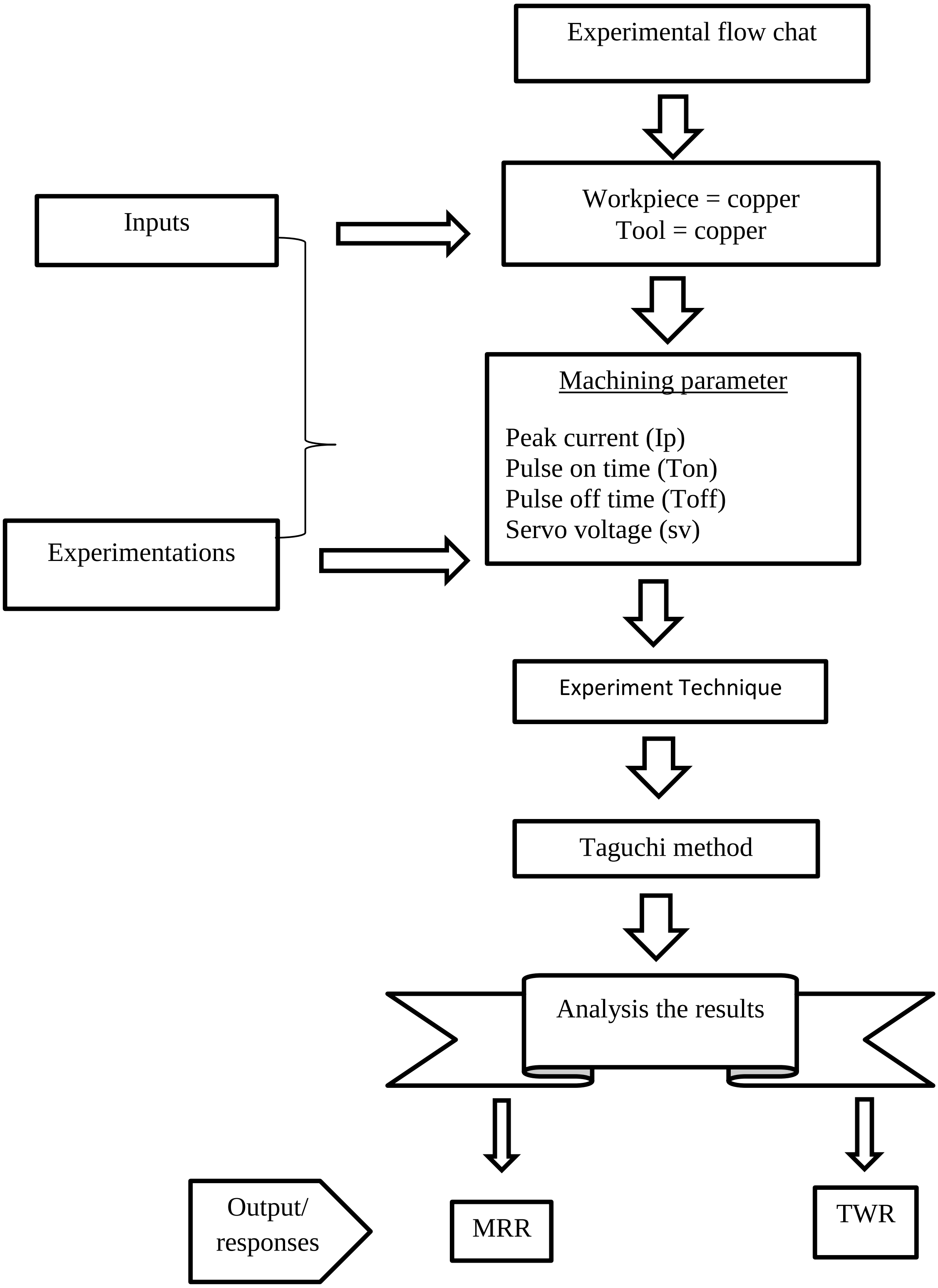

Figure 3.1: Flow Chart Of Experiment

3.3 MATERIAL SELECTION

Material selection is the most important to this experiment because different materials have different working parameters based of their properties. The right selection of the machining material is the most important aspect to take into consideration in processes related to the EDM. From the observation and discussion with partner and supervisor, the electrode material that has been selected is copper while their work pieces also copper.

3.3.1 Electrodes

The important factors in selecting cooper is their high strength-to-weight ratio, resistance to corrosion by many chemicals, high thermal and electrical conductivity, non-toxicity, reflectivity, appearance and ease of formability and of machinability; they are also nonmagnetic.

Copper is a chemical element with the symbol Cu (Latin: cuprum) and atomic number 29. It is a ductile metal with excellent electrical conductivity. Copper is rather supple in its pure state and has a pinkish luster which is (beside gold) unusual for metals, which are normally silvery white. It is used as a heat conductor, an electrical conductor, as a building material and as a constituent of various metal alloys. Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity. Copper is malleable and ductile, a good conductor of heat and, when very pure, a good conductor of electricity. The physical properties of these electrode tools are presented in Table 3.1.

Table 3.1: Physical properties of copper

Property	Copper
Density (g/cm³)	8.904
Melting point (°C)	1084.6
Specific heat (J/Kg.°C)	385
Thermal conductivity (W/m.K)	400
Electrical resistivity (μΩ.cm)	1.678
CTE* linear (μm/m.°C)	16.5

Source: (hascalik and caydas,2007; Jahan et al.,2009; Lee and Li,2001; Lin et al., 2009)

3.3.2 Workpiece Material

Copper as work pieces are steels that are primarily used to make tools used in manufacturing processes as well as for machining metals, woods, and plastics. Copper are generally ingot-cast wrought products, and must be able to withstand high specific loads as well as be stable at elevated temperatures. In case of this project, copper also used as a workpiece to produce mould using EDM machine. The chemical composition of copper is displayed in Table 3.2.

Table 3.2: Chemical composition of copper

Element	**Cu**	**Pb**	**Fe**	**Si**	**Co**	**Sb**	**Zn**	**Sn**
Wt %	99.80	0.0327	0.497	0.0133	0.0102	0.0184	0.005	0.005
Element	**Ni**	**Be**						
Wt %	0.005	0.005						

Source: (hascalik and caydas,2007; Jahan et al.,2009; Lee and Li,2001; Lin et al., 2009)